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GROWTH AND SURVIVAL OF THE HALOPHYTE *SALICORNIA EUROPAEA* L. UNDER SALINE FIELD CONDITIONS[1]

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Abstract. Field investigations were carried out to determine growth and survival rates of *Salicornia europaea* L. in a saline environment at Rittman, Ohio. Collected data indicated that from 62% to 100% of the seedlings within the 3 saline zones investigated did not survive to maturity. Seedling mortality was statistically correlated at $P<0.01$ to rising soil salinity stress during late spring and summer. Plant growth was minimal between April and June, increasing sharply during late summer and fall.

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Salicornia europaea L. is an annual halophyte, in the family Chenopodiaceae, with succulent erect photosynthetic shoots (5–40 cm). The species is widely distributed and is known to inhabit inland and coastal salt marshes of North America, Europe, and Africa (Fernald 1950).

Germination, mortality, and growth of halophytic species are often controlled in nature by the interaction of two environmental factors: soil moisture and soil salinity, which are codeterminants of soil water potential (Waisel 1972). Seed germination in many halophytic species occurs early in the growing season when moisture is plentiful and the soil salinity concentrations are reduced (Barbour 1970, Macke and Ungar 1971). Retardation of seed germination has been attributed to an osmotically induced salinity stress that is reversible (Rivers and Weber 1971, Ungar 1978).

Increased salinity stress due to droughts and to a higher rate of evaporation during summer months may cause rapid changes in the density and diversity of species in halophyte communities (Ungar 1974). Seasonal precipitation patterns are often a major factor determining soil water potentials. This factor in turn affects establishment of seedlings, often increasing the rate of mortality during drought periods (Ungar 1973).

The optimum salinity for growth of some species of halophytes is often between 1% and 2% NaCl (Webb 1966, Langlois 1967, Tiku 1976, Ungar 1978); however, all halophytes exhibit reduced growth when salt concentrations exceed their limits of tolerance (Williams and Ungar 1972, Hansen *et al* (1976). Population dynamics, particularly of inland salt marsh communities, are likely to be greatly affected by the seasonal distribution of precipitation peculiar to each geographic location (Weaver 1918, Ungar 1974). For example, in a salt marsh on the property at Rittman, Ohio, Ungar (1973) related the death of *Salicornia europaea* seedlings to below normal precipitation during the summer months.

The purpose of our investigation was to determine how plant growth and mortality are related to changing field soil salinities during the 1976 growing season.

METHODS AND MATERIALS

Location. The study area is located in a saline marsh formed due to mining operations of the Morton Salt Company plant located in Rittman, Ohio. A shallow salt pan (approximately 10 m x 40 m) was located in the center of the site where we collected field data. The study area as characterized by 4 major vegetation zones: a Meadow zone, a *Hordeum jubatum* zone, an *Atriplex triangularis* zone, and a *Salicornia europaea* zone.

Dynamics of Populations. Monthly visits were made to the study site during the 1976

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growing season, from 12 April to 26 October. Groups of twenty-five 100 cm^2 quadrats were established in each of 3 separate regions of the zone dominated by *Salicornia europaea*. One group was situated in the standing water (5 cm 20 cm deep) of the pan, another was placed in a transitional zone at the water's edge (edge zone), while a third was located near the point of transition with the zone dominated by *Atriplex triangularis* (field zone). We made monthly counts of plants for each quadrat and determined values for mean and standard error of the mean densities for each of the three regions.

Analysis of Dry Weights. On 12 April, 9 May, 6 June, and 14 August, we collected *Salicornia europaea* from the edge and field locations for dry weight comparison. Soil containing numerous rooted specimens was collected from the region adjacent to the *Atriplex* zone and from the region near the edge of the pan water. We took the collections to the laboratory where 100 plants from each group were used for the determination of plant dry weight. Separate root and shoot dry weights were determined on 12 April, 6 June and 14 August 1976. The plants were dried to constant weight at 105 °C in a forced draft drying oven, and the specimens were weighed in groups of 10 to the nearest 0.1 mg with a Mettler (H15) balance.

Field Soil Solution Conductivity. A series of 13 conductivity sensors were implanted in the root zone of the plants approximately 10 cm beneath the soil surface. These were placed along a transect at regular intervals between the meadow and the center of the pan. We made monthly measurements of in situ soil solution conductivity using a Soil Moisture Equipment Corp. #5500 salinity bridge. Samples of pan water were collected and taken to the laboratory for measurements of conductivity with a Radiometer (CDM2d) conductivity meter.

RESULTS

Soil Solution Conductivity. The soil solution conductivity data indicates the presence of a soil salinity gradient. Highest values were recorded from conductivity sensors located in the central area of the pan, and lowest conductivity was measured at sensors located in the meadow (fig 1). The amplitude of the gradient displayed seasonal variability. On 12 April, it ranged from 1.1 mmhos/cm in the meadow to 48.0 mmhos/cm on the pan, while on 14 August, this range had increased from 2.4 mmhos/cm in the meadow to 142.8 mmhos/cm on the pan.

A seasonal fluctuation of soil solution conductivity was apparent at all locations. The sensors located in the meadow zone had the earliest peak of soil solution conductivity, occurring on 6 June. Sensors located in the *Salicornia* zone regis-

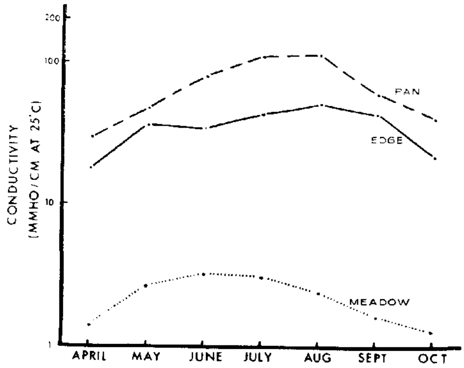

FIGURE 1. Monthly measurements of soil solution conductivity (mmho/cm at 25 °C) made with *in situ* conductivity sensors.

tered a peak in conductivity at the time of the 5 July readings. The remaining sensors displayed their highest values on 14 August. After this mid-summer conductivity peak was attained, a decrease in soil solution conductivity occurred in September and October to levels found earlier in the growing season (fig. 1). Samples of standing water in the pan collected at each visit to the research site displayed a pattern of seasonal conductivity changes independent from that established for the soil solution. For example, April, July, and October soil solution conductivity values were 29.4, 109.9 and 39.5 mmhos/cm, while standing water on the pan at these locations had conductivities of 64, 48, and 23 mmhos/cm over the same time period. Soil moisture levels in all zones were above 50%, ranging from 50.9%to 61.4% over the growing season. These data indicate that these soils did not have a significant soil matric water stress during the period of active growth.

Seedling Density and Mortality. In the *Salicornia* population, bordering the *Atriplex* zone (field), on 12 April 1976, the mean density was 276 plants per 100 cm^2 quadrat (fig. 2). The density of *S. europaea* reached a peak of 362 on 9 May, followed by the greatest mortality recorded for any region during the entire growing season, the reduction in plant density reaching 77% by 6 June. The high mortality early in the growing season resulted in a gradual decrease in plant number stabilized by 14 August, when the mean density was 56 plants per 100 cm² quadrat. The decrease in density in the field zone from 9 May to 26 October was 85%, and in 24% of the plots fewer than 5 plants survived (table 1).

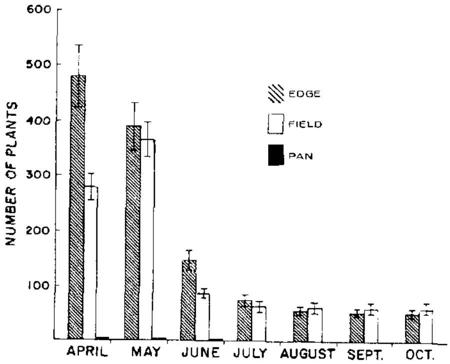

FIGURE 2. Monthly measurements of *Salicornia europaea* population densities (No./100 cm²) in the region adjacent to the *Atriplex triangularis* zone (FIELD), the region at the edge of the pan (EDGE), and the region in the standing water of the pan (PAN). Bars represent standard error of the mean.

A similar fluctuation of density was noted for 25 quadrats situated in the *Salicornia* zone at the water's edge (fig. 2). The mean density in this region on 12 April 1976 was 479 plants per quadrat, a number greater than the mean density of the zone bordering *Atriplex*. Field counts on 9 May revealed a 19% reduction in plant density. The highest mortality for the edge zone occurred between 9 May and 6 June when a 62% reduction in the density of *Salicornia* was observed. A gradual decrease in density followed until 14 August, after which the density of this population remained stable. A 90% decrease in plant density occurred between 12 April and 26 October, and 8% of the quadrats had no survivors (table 1).

The population density of *S. europaea* for the pan region displayed a high degree of variability between quadrats, ranging from 0 to 28 plants per quadrat. On 12 April, the highest density per quadrat was 28, while 70% of the quadrats contained 0 to 4 plants. The mean density per quadrat dropped from a high point of 4.3 plants per quadrat to 0.3 on

TABLE 1

Maximum and minimum survival levels for Salicornia europaea in 100 cm² quadrats in three marsh zones.

Zone		Initial Plant Number (12 April)	Final Plant Number (26 October)
Atriplex Border			
	Min.	230	0*
	Max.	560	150*
Pan Edge			
	Min.	130	0*
	Max.	392	105*
Pan			
	Min.	1	0*
	Max.	28	0*

*These values represent extremes and indicate the very high mortality. Differences in all plots significant at $P<0.01$.

5 July. By 14 August, no *S. europaea* survived in the pan zone (fig. 2).

Dry Weight Analysis. Plants growing in the field and edge zones were analyzed for root and shoot dry weight on 12 April, 6 June, and 14 August (fig. 3). *Salicornia europaea* plants collected on 12 April and 6 June from soils within the field zone had greater dry weights than

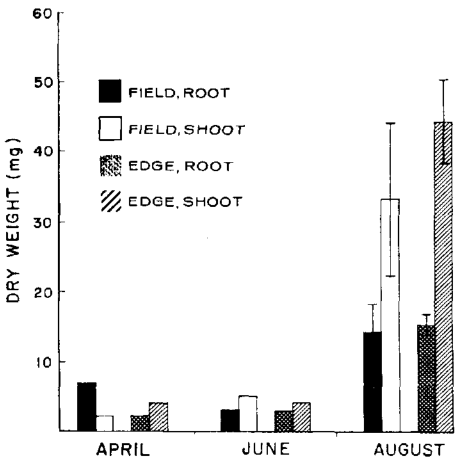

FIGURE 3. Seasonal pattern of root and shoot dry weight accumulation for *Salicornia europaea* plants growing in the region adjacent to the *Atriplex triangularis* zone (FIELD) and in the region at the edge of the pan (EDGE). Bars represent standard error of the mean and are omitted for April and June data because SEM was less than ±5 mg.

plants from the edge zone. Collections on 14 August and 12 September showed an apparent reversal of the early season pattern of growth. Shoot dry weights for *S. europaea* plants growing in the edge zone were 25% greater than for those growing in the field zone on 14 August, and by September, the disparity between the two regions increased to 75%.

The root:shoot ratio for *Salicornia europaea* collected from the region adjacent to the *Atriplex* zone decreased from 0.60 on 6 June to 0.42 on 14 August. *Salicornia europaea* plants collected from the region at the edge of the pan showed a similar trend, with their root:shoot ratio decreasing from 0.75 on 6 June to 0.34 on 14 August.

DISCUSSION

A lower density was recorded for *Salicornia europaea* plants in April, May, and June 1976 for the field zone, bordering the region dominated by *Atriplex triangularis*, than in the region at the water's edge. The initially higher density of *S. europaea* in the edge zone was probably due to higher soil moisture levels that facilitated seedling establishment. In August, September, and October, *S. europaea* plants growing in the field zone displayed up to 14% higher average densities than those inhabiting the edge zone. The survival of *S. europaea* in different regions of the site was low, ranging from 0 to 38% in any single quadrat. Plant death was significantly correlated at the $P = .01$ level (Field, $r = 0.8887$, Edge, $r = 0.7628$, Pan, $r = 0.6311$) with the increase in soil salinity from May to August. A similar situation was described by Weaver (1918), Ungar (1967), and McMahon and Ungar (1978) for populations of *Suaeda depressa* and *Atriplex triangularis*, indicating that seedling mortality is closely related to an increase in soil salinity levels.

Despite the presence of an abundance of floating *Salicornia europaea* seedlings in April and May in the pan zone, few plants rooted in the submerged areas. In April, mean conductivity readings for the pan water was 64 mmhos/cm, while the edge and field zones displayed salinities of approximately 39.8 and 18.9 mmhos/cm respectively. The very low rate of *S. europaea* seedling establishment observed in the pan region was probably due to the high salinity of the standing water early in the growing season and the high soil solution conductivities on the pan, reaching a mean of 129 mmhos/cm by August.

Seasonal changes in dry weight accumulation observed in this investigation appear to be directly related to soil salinity stress. The greatest increase in dry matter production occurred between the August and September sampling period when the soil salinity levels began declining. Although seeds of *S. europaea* were found germinating in March, little dry weight production occurred until the latter part of the growing season. Data collected during the 1977 growing season corroborated these findings, indicating that there is essentially no increase in dry matter production between early and mid-summer (Ungar, unpublished data). In the late summer between 7 August and 16 September, dry weights increased to four times the previous value, and these values doubled again between 16 September and 10 October. This rapid increase in biomass production late in the growing season may be a mechanism that has evolved in this species to avoid decreasing water potentials and the accompanying osmotic and ionic stress during the early and mid-summer months. The very low increase in dry weight between May and July indicates that the low soil water potentials at this time were limiting to plant growth. This long term cessation of plant growth during the middle of the growing season has not been previously reported for halophytes. The period of maximum growth occurred just prior to the time of flower and seed production. Waisel (1972) and Chapman (1974) have reported that halophytes often exhibit stunted growth when found under saline conditions approaching their tolerance limits, indicating that increased salinity stress during the summer months could account for the decreased growth and high mortality found for these populations of *S. europaea*.

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